Comparison and Optimal Design of SSSC Controller Based on ICA and PSO for Power System Dynamic Stability Improvement

Ali Ajami*1, **Behrouz Mohammadzadeh***2, **Reza Gholizadeh***3, and **R. Reza Ahrabi***4, Non-members

ABSTRACT

A new imperialist competitive algorithm (ICA)-based approach is proposed for optimal selection of the static synchronous series compensator (SSSC) damping controller parameters in order to shift the closed loop eigenvalues toward the desired stability. The optimal selection of the parameters for the SSSC controllers is converted to an optimization problem which is solved by recently developed evolutionary ICA method. This optimization algorithm has a strong ability to find the most optimistic results for dynamic stability improvement. Single machine infinite bus (SMIB) system has been considered to examine the operation of proposed controllers. The input power variation of generator is considered as a disturbance. The effectiveness of the proposed controller for damping low frequency oscillations is tested and results compared with particle swarm optimization (PSO). Also, the performance of proposed method is tested in different loading conditions. In addition, the potential and superiority of the proposed ICA method over the PSO is demonstrated. Also, performance of ICA in 10 times run is the same as in 1 time run. The simulation results analysis show that the designed ICA based SSSC damping controller has an excellent capability in damping low frequency oscillations and enhance rapidly and greatly the dynamic stability of the power systems, in compare to PSO technique.

Keywords: SSSC, Imperialist competitive algorithm, Particle swarm optimization, Power system stability enhancement, Low frequency oscillation damping.

1. INTRODUCTION

Electromechanical oscillations in power systems are a main problem that has been challenging researchers for years. These oscillations may be very poorly damped in some cases, resulting in mechanical fatigue at the equipment and unacceptable power variations the across transmission lines. For this reason, the use of the controllers to provide better damping of electromechanical oscillations is major challenges [1]. In the past three decades, power system stabilizers (PSSs) have been broadly used in order to damp low frequency oscillations and increase dynamical stability. PSSs have proven to be efficient in performing their assigned tasks, which operate on the excitation system of generators. However, PSSs may unfavorably have an effect on the voltage profile, may result in a leading power factor, and may be unable to control oscillations caused by large disturbances such as three phase faults which may occur at the generator terminals [2, 3]. Some of these are due to the limited capability of PSS, in damping only local modes and not inter area modes of electromechanical oscillations [4]. Recently, due to the fast progress in the field of power electronics had opened new opportunities for the application of the flexible AC transmission systems (FACTS) devices. For this reason, FACTS devices as one of the most useful ways to improve power system operation controllability and solving various power system steady state control problems, such as voltage regulation, transfer capability enhancement, power flow control and damping of power system oscillations [2, 5, 6]. Among FACTS family, SSSC is one of the important types, which can be installed in series in the transmission lines. Although the main function of SSSC is to control of power flow but it can is used, as an impressive devise, to control of power system dynamical stability [7]. The application of SSSC based controller for power oscillation damping, dynamical stability improvement and frequency stabilization can be found in several references [6-8]. Recently the optimization methods to obtain the optimal values of controller parameters are used. These optimization techniques for achieved SSSC's controllers have been published in following literatures. Genetic algorithm (GA) and PSO in [9-11] were investigated, respectively. ICA is a new evolutionary optimization method which is inspired by imperialistic competition [12]. It is a very strong method for optimization and has emerged as a useful tool for engineering optimization. Over the last 6 years, after it was first introduced, this algorithm

Manuscript received on December 25, 2013 ; revised on April 14, 2014.

*The authors are with Department of Electrical Engineering, Azarbaijan Shahid Madani University, Tabriz, Iran, E-mail: yoshimasu@waseda.jp[1], mohammadzadeh@azaruniv.edu[2], rezagholizadeh@azaruniv.edu[3], and ahrabi@azaruniv.edu[4].

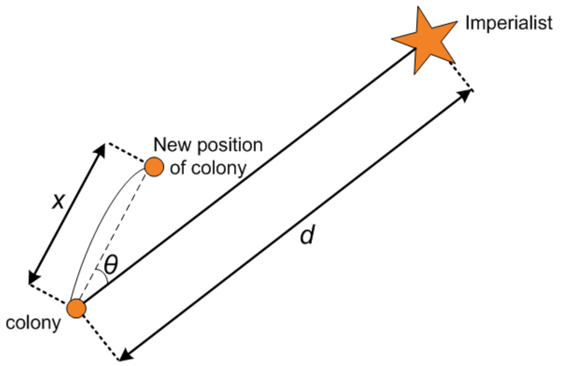

Fig.1: *Motion of colonies toward their relevant imperialist.*

has been used in a variety of research areas [13-17] and has been proven as a promising tool for optimization purposes. According to [12, 13], the ICA has better results than the genetic algorithm (GA) and PSO [18], respectively. In this study, SSSC damping controller design using ICA to find the optimal parameters of lead-lag controller is presented. To show effectiveness of ICA method, it is compared with PSO technique. SSSC based damping controller is considered as an optimization problem and both, ICA and PSO techniques are used for searching the optimal values of controller parameters. The effectiveness and robustness of the proposed controller are demonstrated through time-domain simulation under various loading conditions and large disturbance. Evaluation of results show that the ICA based tuned damping controller has good performance for a wide range of operating conditions and is superior to the controller designed using PSO technique.

2. DESCRIPTION OF THE OPTIMIZATION METHODS

2.1 ICA PROPOSED APPROACH

As illustrated before, imperialist competitive algorithm is a new evolutionary optimization method which is inspired by imperialistic competition. Like other evolutionary algorithms such as PSO, GA, etc., it starts with an initial population which is called country and is divided into two types of colonies and imperialists which together form empires. Imperialistic competition among these empires forms the proposed evolutionary optimization algorithm. During this competition, weak empires collapse and powerful ones take possession of their colonies. Imperialistic competition converges to a state in which there exists only one empire and colonies have the same cost function value as the imperialist. After dividing all colonies among imperialists and creating the initial empires, these colonies start moving toward their related imperialist state which is called assimilation

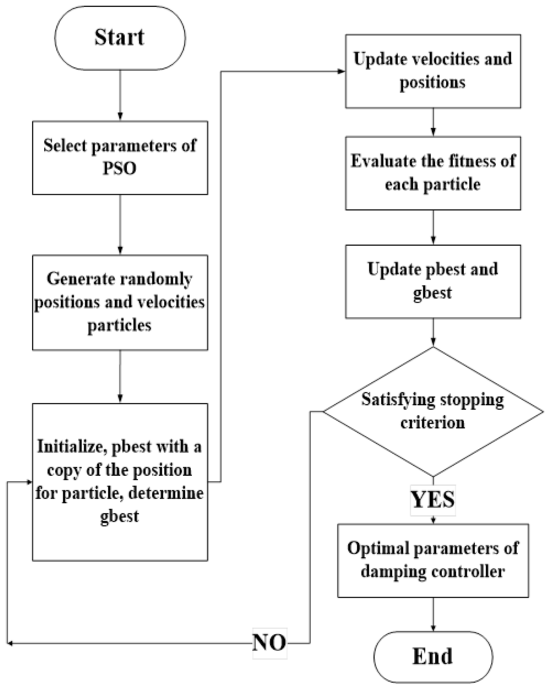

Fig.2: *Flowchart of PSO algorithm.*

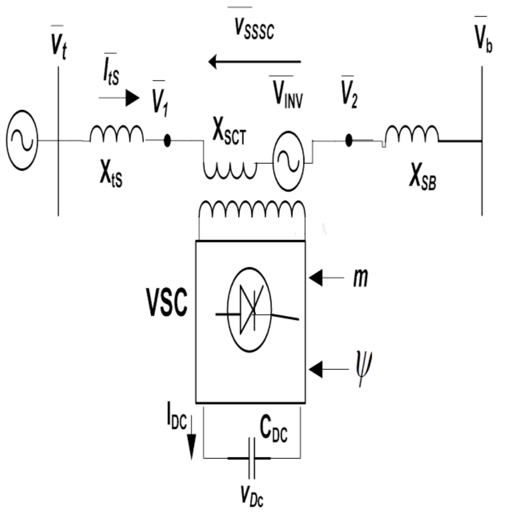

Fig.3: *SSSC installed in a SMIB system.*

policy [19]. Fig.1 shows the movement of a colony towards the imperialist. In this movement, θ and x are random numbers with uniform distribution as showed in (1) and d is the distance between colony and the imperialist.

$$x \approx U(0, \beta \times d), \qquad \theta \approx U(-\gamma, \gamma) \tag{1}$$

In the above equation, β and γ are parameters that modify the area that colonies randomly search around the imperialist. The total power of an empire

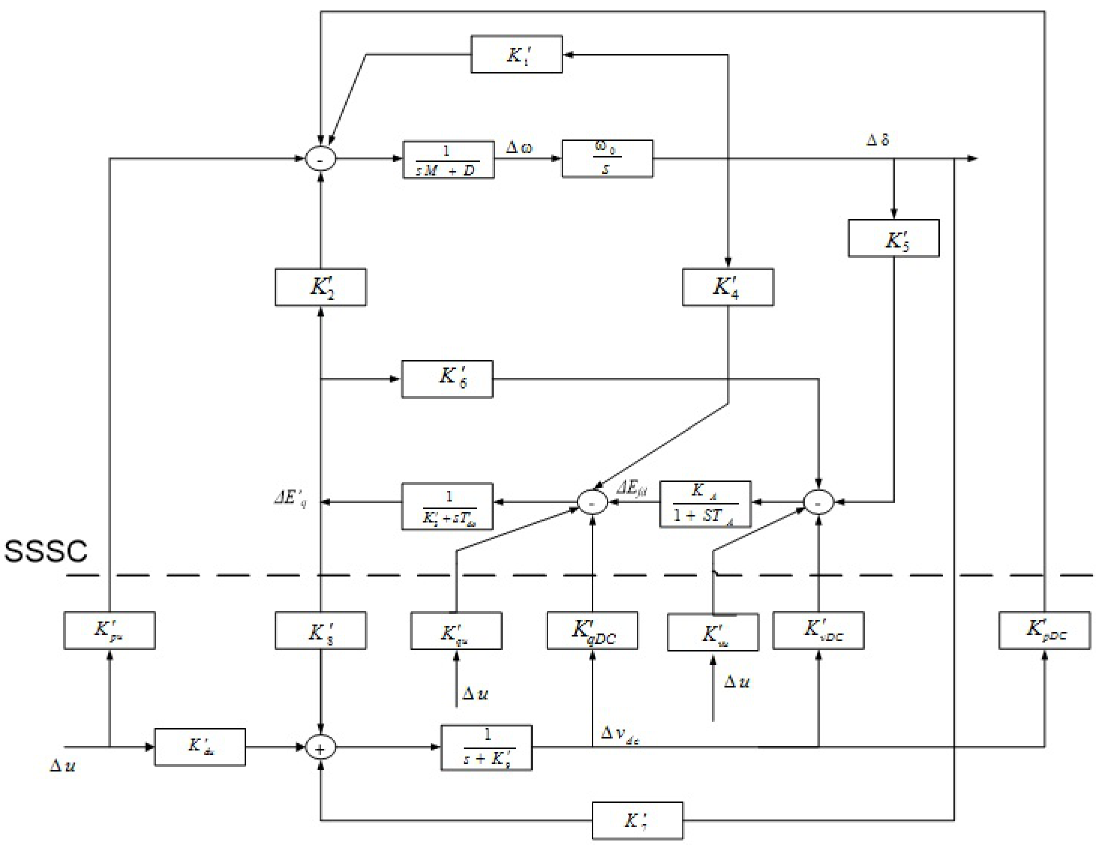

Fig.4: *Modified Phillips-Heffron model of a SMIB system equipped with SSSC.*

depends on both the power of the imperialist country and the power of its colonies which is shown in (2).

$$T.C.n = Cost(imperialist\ _n) + \zeta_{ica} mean(Cost\ (colonoes\ of\ impire\ _n)) \quad (2)$$

The pseudo code of imperialist competitive algorithm is as follows:

1. Select some random points on the function and initialize the empires.
2. Move the colonies toward their relevant imperialist (Assimilation).
3. Randomly change the position of some colonies (Revolution).
4. If there is a colony in an empire which has lower cost than the imperialist, exchange the positions of that colony and the imperialist.
5. Unite the similar empires.
6. Compute the total cost of all empires.
7. Pick the weakest colony (colonies) from the weakest empires and give it (them) to one of the empires (Imperialistic competition).
8. Eliminate the powerless empires.
9. If stop conditions satisfied, stop, if not go to 2.

2.2 OVER VIEW OF PSO ALGORITHM

A novel population based optimization approach, called particle swarm optimization (PSO) approach, was introduced first in [18]. Defining the principle of PSO is out of this papers scope and the complete review is given in several papers for instance in [18, 20]. Fig. 2 shows the flowchart of the PSO technique.

3. DESCRIPTION OF CASE STUDY SYSTEM

Fig. 3 shows a single-machine infinite-bus (SMIB) power system equipped with a SSSC. The SSSC consists of a boosting transformer with a leakage reactance X_{SCT}, a three-phase GTO based voltage source converter (V_{INV}), and a DC capacitor (C_{DC}). The two input control signals to the SSSC are m and Ψ. Signal m is the modulation ratio of the pulse width modulation (PWM) based VSC. Also, signal Ψ is the phase of the injected voltage and is kept in quadrature with the line current (inverter losses are ignored). Therefore, the compensation level of the SSSC can be controlled dynamically by changing the magnitude of the injected voltage. Hence, if the SSSC is equipped with a damping controller, it can be effective in enhancing power system dynamical stability.

3.1 POWER SYSTEM NONLINEAR MODEL WITH SSSC

The dynamic model of the SSSC is required in order to study the effect of the SSSC for increasing the small signal stability of the power system. The system data is given in the Appendix. By applying Park's transformation and neglecting the resistance and transients of the transformer, nonlinear dynamic model of the power system with SSSC is given as [8]:

$$\bar{I}_{ts} = I_{tsd} + jI_{tsq} = I_{TS}\angle\varphi \tag{3}$$

$$\bar{V}_{INV} = mkV_{DC}(cos\Psi + jsin\Psi) = mkV_{DC}\angle\Psi \tag{4}$$

$$\begin{aligned}\Psi &= \varphi \pm 90^{\circ} \\ \dot{V}_{DC} &= \frac{dV_{DC}}{dt} = \frac{I_{DC}}{C_{DC}}\end{aligned} \tag{5}$$

$$\dot{V}_{DC} = \frac{mk}{c_{DC}}(I_{tsd}cos\Psi + I_{tsq}sin\Psi) \tag{6}$$

Where, k is the ratio between AC and DC voltages and is dependent on the inverter structure. The nonlinear model of the SMIB system as shown in Fig. 3 has been introduced by following equations [8]:

$$\dot{\delta} = \omega_b\omega \tag{7}$$

$$\dot{\omega} = (P_m - P_e - D\omega)/M \tag{8}$$

$$\dot{E}_q^{''} = (-E_q + E_{fd})/T_{do}^{''} \tag{9}$$

$$\dot{E}_{fd} = -\frac{1}{TA}E_{fd} + \frac{K_A}{T_A}(V_{to} - V_t) \tag{10}$$

where,

$$\begin{aligned}P_e &= E_q^{''}I_{tsq} + (X_q - X_d^{''})I_{tsd}I_{tsq} \\ E_q &= E^{''} + (X_d - X_d^{''})I_{tsd} \\ V_t &= \sqrt{(E_q^{''} - X^{''}dI_{tsd})^2 + (X_qI_{tsq})^2}\end{aligned}$$

3.2 POWER SYSTEM LINEARIZED MODEL

Linearizing By applying linearization process Eq. (3)-(10), around operation point of case study system, state space model of the system can be achieved, as follows [8]:

$$\Delta\dot{\delta} = \omega_b\Delta\omega \tag{11}$$

$$\Delta\dot{\omega} = (-\Delta P_e - D\Delta\omega)/M \tag{12}$$

$$\Delta\dot{E}_q^{''} = (-\Delta E_q + \Delta E_{fd})/T_{do}^{''} \tag{13}$$

$$\Delta\dot{E}_{fd} = -\frac{1}{T_A}\Delta E_{fd} - \frac{K_A}{T_A}\Delta V_t \tag{14}$$

$$\begin{aligned}\Delta\dot{V}_{DC} =& K_7^{'}\Delta\delta + K_8^{'}\Delta E_q^{''} + K_9^{'}\Delta V_{DC} \\ &+ K_{dm}^{'}\Delta m + K_{d\Psi}^{'}\Delta\Psi\end{aligned} \tag{15}$$

where,

$$\begin{aligned}\Delta P_e =& K_1^{'}\Delta\delta + K_2^{'}\Delta E_q^{''} + K_{pDC}^{'}\Delta V_{DC} + K_{pm}^{'}\Delta m \\ &+ K_{p\Psi}^{'}\Delta\Psi \\ \Delta E_q =& K_4^{'}\Delta\delta + K_3^{'}\Delta E_q^{''} + K_{qDC}^{'}\Delta V_{DC} + K_{qm}^{'}\Delta m \\ &+ K_{q\Psi}^{'}\Delta\Psi \\ \Delta V_t =& K_5^{'}\Delta\delta + K_6^{'}\Delta E_q^{''} + K_{vDC}^{'}\Delta V_{DC} + K_{vm}^{'}\Delta m \\ &+ K_{v\Psi}^{'}\Delta\Psi\end{aligned}$$

$K_1^{'}$, $K_2^{'}$... $K_9^{'}$, $K_{pu}^{'}$, $K_{qu}^{'}$ and $K_{vu}^{'}$ are linearization constants and are dependent on system parameters and the operating condition. The state space model of power system is given by:

$$\dot{x} = Ax + Bu \tag{16}$$

where x and u are state vector and control vector, respectively. A and B are:

$$\begin{aligned}x =& [\Delta\delta \;\; \Delta\omega \;\; \Delta E_q^{''} \;\; \Delta E_{fd} \;\; \Delta V_{DC}]^T \\ u =& [\Delta m \;\; \Delta\Psi]^T\end{aligned}$$

$$\mathrm{A} = \begin{bmatrix} 0 & w_b & 0 & 0 & 0 \\ -\frac{K_1^{'}}{M} & -\frac{D}{M} & -\frac{K_2^{'}}{M} & 0 & -\frac{K_{pDC}^{'}}{M} \\ -\frac{K_4^{'}}{T_{do}^{''}} & 0 & -\frac{K_3^{'}}{T_{do}^{''}} & \frac{1}{T_{do}^{''}} & -\frac{K_{qDC}^{'}}{T_{dq}^{''}} \\ -\frac{K_AK_5^{'}}{T_A} & 0 & -\frac{K_AK_6^{'}}{T_A} & -\frac{1}{T_A} & -\frac{K_AK_{vDC}^{'}}{T_A} \\ K_7^{'} & 0 & K_8^{'} & 0 & K_9^{'} \end{bmatrix},$$

$$\mathrm{B} = \begin{bmatrix} 0 & 0 \\ -\frac{K_{pm}^{'}}{M} & -\frac{K_{p\Psi}^{'}}{M} \\ -\frac{K_{qm}^{'}}{T_{do}^{''}} & -\frac{K_{q\Psi}^{'}}{T_{do}^{''}} \\ -\frac{K_AK_{vm}^{'}}{T_A} & -\frac{K_AK_{v\Psi}^{'}}{T_A} \\ K_{dm}^{'} & K_{d\Psi}^{'} \end{bmatrix}$$

The block diagram of the linearized dynamic model of the SMIB power system installed SSSC is shown in Fig. 4.

4. SSSC BASED PROPOSED CONTROLLER STRUCTURE

The damping controller is designed in order to improve the damping torque. The SSSC damping controller structure is shown in Fig. 5, where u can be m or Ψ. It comprises gain block, signal-washout block and lead-lag compensator [5]. Values of controller parameters should be kept within specified limits. In this paper, an ICA is proposed for the optimal computation of controller parameters.

4.1 OPTIMIZATION PROBLEM

In the proposed method, we must tune the SSSC controller parameters optimally to improve overall system dynamic stability in a robust way under 4

different operating conditions. For our optimization problem, an eigenvalue based objective function reflecting the combination of damping factor and damping ratio is considered as follows:
Objectivefunction :

$$j = \sum_{i=1}^{Np}(\sigma_0 - \sigma_i)^2 + a\sum_{i=1}^{Np}(\varsigma_0 - \varsigma_i)^2 \qquad (17)$$

σ_i and ς_i are the real part and the damping ratio of the ith eigenvalue, respectively. The value of σ_0 determines the relative stability in terms of damping factor margin provided for constraining the placement of eigenvalues during the process of optimization and ς_0 is the desired minimum damping ratio which is to be achieved. The closed loop eigenvalues are placed in the region to the left of dashed line as shown in Fig. 6. It is necessary to mention here that only the unstable or lightly damped electromechanical modes of oscillations are relocated. The design problem can be formulated as the following constrained optimization problem, where the constraints are the controller parameters bounds: Minimize objective function

For the lead-lag controller subject to:

$$\begin{aligned} K_d^{min} &\le K_d \le K_d^{max} \\ T_1^{min} &\le T_1 \le T_1^{max} \\ T_2^{min} &\le T_2 \le T_2^{max} \\ T_3^{min} &\le T_3 \le T_3^{max} \\ T_4^{min} &\le T_4 \le T_4^{max} \end{aligned} \qquad (18)$$

Typical ranges of the optimized parameters of lead-lag controller are [-100 100] for K_d, [0.01 1.5] for T_1, T_2, T_3 and T_4. The proposed approaches employ ICA and PSO algorithms to solve this optimization problem and search for an optimal or near optimal set of controller parameters. The optimization of SSSC controller parameters is carried out by evaluating the objective function as given in (17), for the lead-lag controller.

5. SIMULATION RESULTS

5.1 APPLICATION OF THE ICA AND PSO TO THE DESIGN PROCESS

Based on singular value decomposition (SVD) analysis in [21] modulating Ψ has an excellent capability in damping low frequency oscillations in comparison with other input of SSSC, thus in this paper, Ψ is modulated in order to damping controller design. In this paper, the values of σ_0, ς_0 and a are taken as -2, 0.5 and 10, respectively. In order to acquire better performances of ICA and PSO, proper parameters are given in Table 1. The ICA and PSO were applied to search for the optimal parameter settings of the Ψ supplementary controller so that the objective function is optimized. The both algorithms are run 1 and 10 times and the best solution based on the minimum objective function (17) is selected. Table 2 shows the optimal controller parameters for 1 and average of 10 runs. Fig. 7 shows the cost function values for ICA and PSO optimization methods when the program is run once and 10 times. As it is seen in this Figure, for the same objective function, ICA cost value is less than PSO. Also, its performance in 10 times run is the same as in 1 time run.

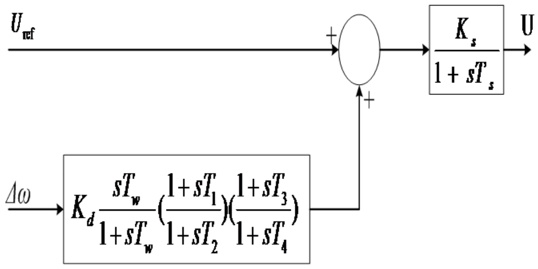

Fig.5: *Lead-lag damping controller structure.*

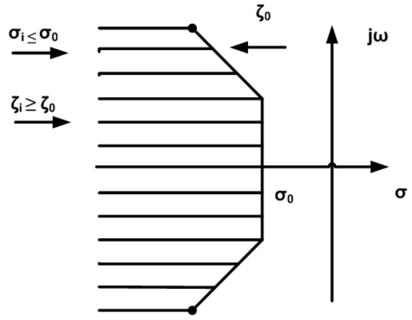

Fig.6: *Region of eigenvalue location for objective function.*

Table 1: *Algorithms proper parameters.*

PSO method		ICA method	
C1	1.4	number of countries	100
C2	1.4	number of initial imperialists	8
W_{MAX}	0.9	assimilation coefficient (β)	3
W_{MIN}	0.4	ς_{ica}	0.2
Iteration	100	number of decades(iteration)	100

5.2 TIME DOMAIN SIMULATION

It should be noted, that the optimization process for both methods has been carried out with the system operating at nominal loading conditions given in Table 3. To assess the effectiveness and robustness of the proposed controllers, simulation studies are carried out for various loading conditions of Table 3. The eigenvalues of electromechanical modes with ICA and PSO controllers at 4 different loading conditions are given in Table 4. By using objective function (17), the electromechanical mode eigenvalues have been shifted to the left side of σ_0 in s-plane

Table 2: *The optimal parameter settings of the PSO and proposed ICA controller with 1 and average of 10 runs based on the objective function (17).*

Controller Parameters		K_d	T_1	T_2	T_3	T_4	Cost
PSO	1-run	-76.0000	1.0500	0.1589	1.5000	0.1580	9.3073
	10-runs	-62.0000	1.0510	0.1638	1.4800	0.1638	8.9583
ICA	1-run	-30.0000	0.0500	0.1312	1.5000	1.4067	4.6253
	10-runs	-22.0000	1.0569	0.3984	0.3400	0.6592	4.6148

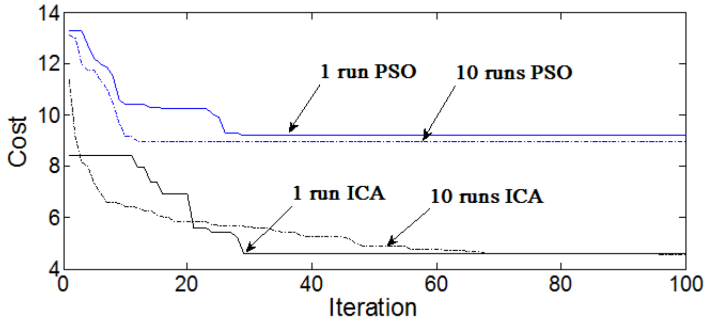

Fig.7: *The convergence for objective function minimization using the ICA and PSO techniques.*

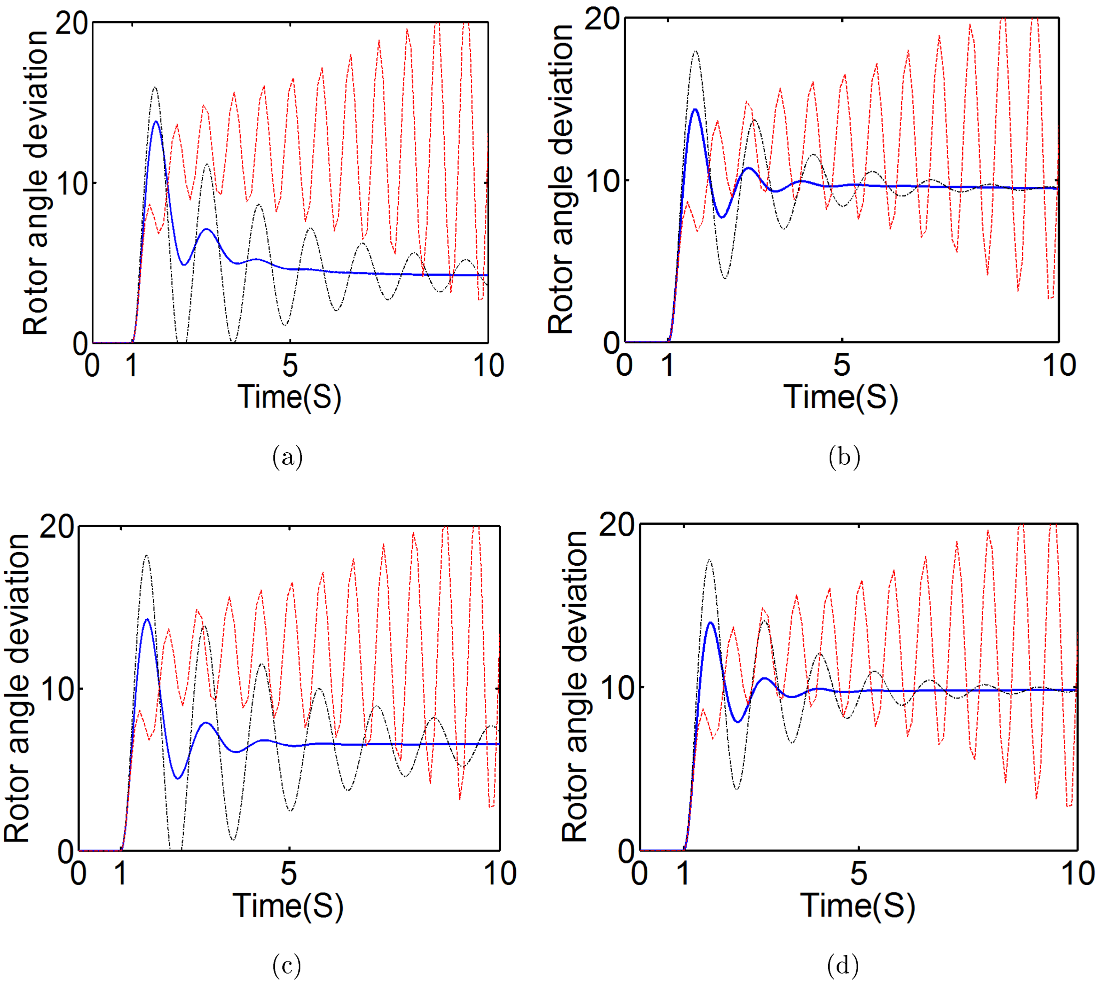

Fig.8: *Rotor angle deviation ($\Delta\delta$) for (a) case 1 (b) case 2 (c) case 3 and (d) case 4 with Ψ controller ; solid (ICA controller), dash-dotted (PSO controller) and dashed (without controller).*

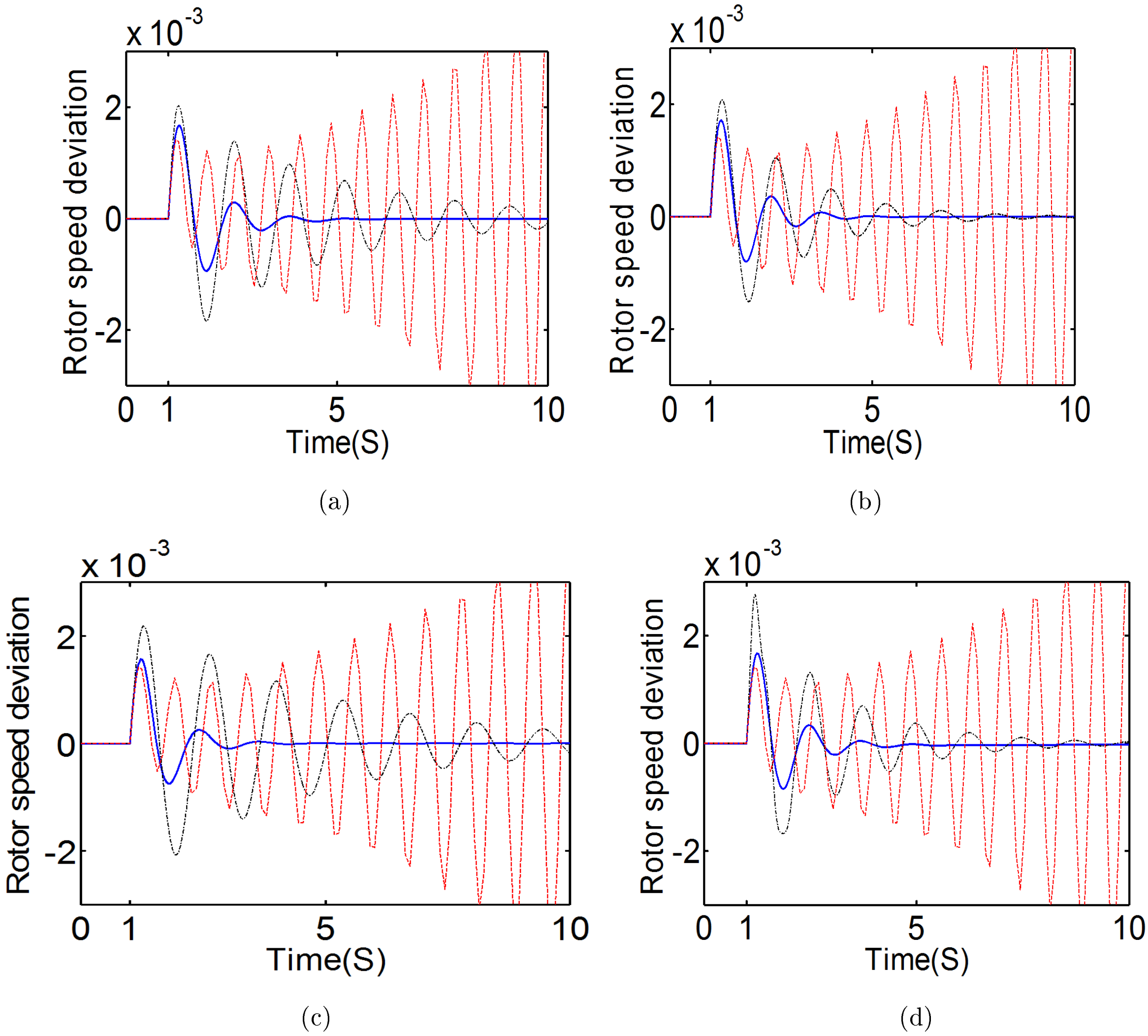

Fig.9: *Rotor speed deviation ($\Delta\omega$) for (a) case 1 (b) case 2 (c) case 3 and (d) case4 with Ψ controller ; solid (ICA controller), dash-dotted (PSO controller) and dashed (without controller).*

Table 3: *System loading Conditions.*

Loading Conditions	P (P.U.)	Q (P.U.)
Case1 (Nominal)	1	0.15
Case2 (Light)	0.3	0.015
Case3 (Heavy)	1.1	0.4
Case4 (Power factor)	0.7	-0.03

and the system damping with the proposed methods greatly improved and increased. The system behavior due to the utilization of the proposed controllers has been tested by applying 10% step increase in mechanical power input at t = 1 s. The system response to this disturbance under 4 different loading conditions for speed deviation, rotor angle deviation and power deviation with Ψ based controller, as well as, with and without controllers, are shown in Figures 8-10. It is obvious that the open loop system is unstable, where as the proposed ICA and PSO controllers stabilize the system. It can be observed from Figs. 8-10 that the performance of the system is better with the proposed ICA optimized lead-lag controller compared to the PSO optimized lead-lag controller. Also, simulation results clearly illustrate, proposed objective function-based optimized SSSC controller with ICA, has good performance in damping low-frequency oscillations and stabilizes the system quickly in compared to the PSO method.

6. CONCLUSIONS

In this paper, the optimal SSSC controller parameters design was converted into an optimization problem, which was solved using the ICA technique with the eigenvalue based time domain objective function. The effectiveness of the proposed SSSC controller for damping low frequency oscillations of a power system were demonstrated by a weakly connected example power system subjected to a disturbance, an increasing mechanical power. The designed ICA and PSO controllers are applied to the system and their responses are compared with each other. Results from

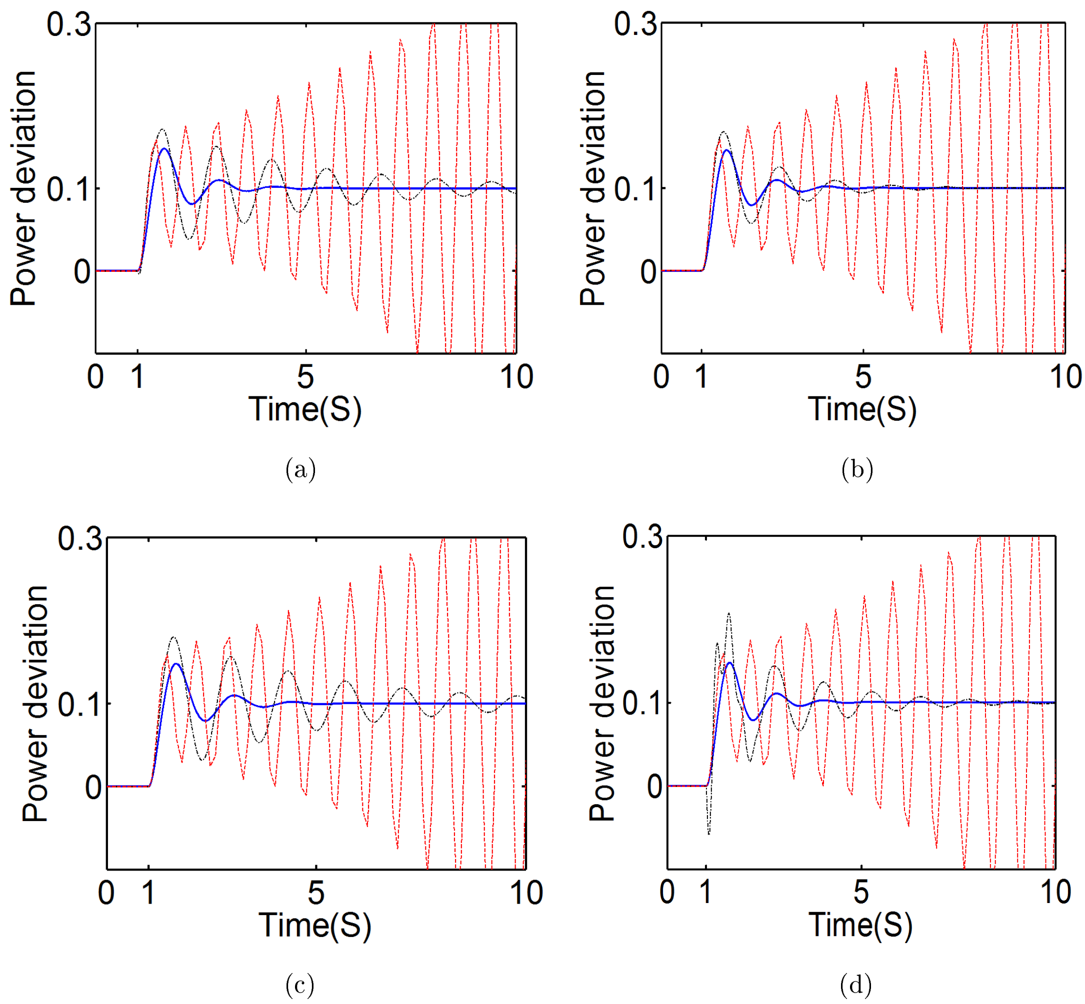

Fig.10: *Active power deviation (Δ P_e) responses for (a) case 1 (b) case 2 (c) case 3 and (d) case 4 with Ψ controller ; solid (ICA controller), dash-dotted (PSO controller) and dashed (without controller).*

Table 4: *Eigenvalues of the electromechanical modes with controllers.*

Loading conditions	Case1	Case2	Case3	Case4
Without controller	-9.7188±j14.5590 **1.2231±j4.8569** -0.6756	-10.1261±j16.4602 **1.2592±j5.0855** -0.0197	-9.2385±j13.2122 **1.1200±j4.6027** -1.8010	-10.0705±j15.7684 **1.2470±j5.1836** -0.0721
PSO controller	-100.7200 -22.9300 -7.88±j15.49 **-0.04±j4.87** -2.30±j0.18 -0.6500	-98.9743 -20.8748±j16.5709 -5.4450±j10.4979 -0.2790±j5.3214 -5.6802 **-0.0197**	-99.9158 -20.0000 -8.2027±j12.8606 *-0.0820±j 4.6924* -8.6736 -1.6848	-91.0100 -20.7700 -9.1516±j16.1008 *-0.0300±j5.3020* -1.6110±j0.0710 -0.0700
ICA controller	-100.1300 -20.6000 -20.0000 -9.3300±j14.7200 -1.2400±j4.7900 -0.6800 **-0.6700**	-100.0000 -20.0500 -20.0000 -10.1000±j16.4700 -1.2600±j5.0800 -0.6700 **-0.0200**	-99.9240 -21.1383 -20.0000 -8.6949±j13.5235 -1.7983 -1.1337±j4.4837 **-0.6876**	-100.1600 -20.1300 -20.0000 -9.9200±j15.8200 -1.2500±j5.1700 -0.6700 **-0.0700**

time domain simulations show that the low frequency oscillations can be easily damped for power systems with the proposed ICA method. The comparison of presented results based on different optimization methods shows the effectiveness of proposed ICA controller in low frequency oscillations damping under all of loading conditions and large disturbances.

APPENDIX

The nominal parameters and operating condition of the case study system are:

Generator

$\mathbf{M}$ = 8.0 MJ/MVA
$\mathbf{D}$ = 0.0
$\mathbf{T'}_{do}$ = 5.044 s
$\mathbf{f}$ = 60 Hz
$\mathbf{V}$ = 1.05 pu
$\mathbf{x}_d$ = 1.0 pu
$\mathbf{x}_q$ = 0.6 pu
$\mathbf{x'}_d$ = 0.3 pu
$\mathbf{p}_e$ = 0.8

Excitation System

$\mathbf{K}_A$ = 100
$\mathbf{T}_A$ = 0.05 s

Transmission Line

$\mathbf{X}_{ts}$ = 0.35 pu
$\mathbf{X}_{SB}$ = 0.6 pu

SSSC

$\mathbf{C}_{DC}$ = 0.25
$\mathbf{V}_{DC}$ = 1
$\mathbf{K}_S$ = 1.2
$\mathbf{T}_S$ = 0.05
$\mathbf{T}_w$ = 0.01
$\mathbf{X}_{SCT}$ = 0.15

References

[1] R. A. Ramos, A. C. P. Martins, and N. G. Bretas, "An improved methodology for the design of power system damping controllers," *IEEE Trans. Power Syst.*, vol. 20, no. 4, pp. 1938-1945, Nov. 2005.

[2] A. T. Al-Awami, Y. L. Abdel-Magid, and M. A. Abido, "A particle swarm based approach of power system stability enhancement with unified power flow controller," *Int. J. Elect. Power Energy Syst.*, vol. 29, no. 3, pp. 251-259, Mar. 2007.

[3] P. M. Anderson, and A. A. Fouad, *Power System Control and Stability*. IEEE Press, 1994.

[4] A. J. F. Keri, "Unified power flow controller: modelling and analysis," *IEEE Trans. Power Del.*, vol. 14, no. 2, pp. 648-654, Apr. 1999.

[5] H. Shayeghi, H. A. Shayanfar, S. Jalilzadeh, and A. Safari, "A PSO based unified power flow controller for damping of power system oscillations," *Energy Convers. Manag.*, vol. 50, pp. 2583-2592, Oct. 2009.

[6] N. Hingorani, L. Gyugyi, *Understanding FACTS: concepts and technology of flexible AC transmission systems*. New York, IEEE press, 2000.

[7] L. Gyugyi, C. D. Schauder, K. Sen, "Static synchronous series compensator: a solid-state approach to the series compensation of transmission lines," *IEEE Trans. Power Del.*, vol. 12, no. 1, pp. 406-417, Jan. 1997.

[8] H. F. Wang, "Design of SSSC damping controller to improve power system oscillation stability," *IEEE AFRICON*, pp. 495-500, 1999.

[9] K. Hongesombut, Y. Mitani, and K. Tsuji, "Power system stabilizer tuning in Multi-Machine power system based on a minimum phase control loop method and genetic algorithm," *Power Syst. Computation Conf.*, 2002, pp. 24-28.

[10] A. Kazemi, M. Ladjevardi, and M. A. S. Masoum, "Optimal selection of SSSC based damping controller parameters for improving power system dynamic stability using genetic algorithm," *Iranian J. Sci. Technology Trans. B Eng.*, vol. 29, no. B1, pp. 1-10, Feb. 2005.

[11] S. Panda, and N.P. Padhy, "A PSO-based SSSC controller for improvement of transient stability performance," *Int. J. Intelligent Technologies*, vol. 2, no. 1, pp. 28-35, 2007.

[12] E. Atashpaz-Gargari, and C. Lucas, "Imperialist competitive algorithm: an algorithm for optimization inspired by imperialistic competition," *IEEE Congr. Evol. Computation*, 2007, pp. 4661-4667.

[13] E. Atashpaz, F. Hashemzadeh, R. Rajabioun, and C. Lucas, "Colonial competitive algorithm: a novel approach for PID controller design in MIMO distillation column process," *Int. J. Intelligent Computing Cybernetics*, vol. 1, no. 3, pp. 337-355, 2008.

[14] R. Jahani, "Optimal placement of unified power flow controller in power system using imperialist competitive algorithm," *Middle-East J. Scientific Research*, vol. 8, no. 6, pp. 999-1007, Jun. 2011.

[15] H. C. Nejad, and R. Jahani, "A new approach to economic load dispatch of power system using imperialist competitive algorithm," *Australian J. Basic Applied Sci.*, vol. 5, no. 9, pp. 835-843, Sept. 2011.

[16] E. Bijami, J. A. Marnani, and S. Hosseinnia, "Power system stabilization using model predictive control based on imperialist competitive algorithm," *Int. J. Tech. Physic Problems Eng.*,

vol. 3, pp. 45-51, Dec. 2011.

[17] M. H. Etesami, N. Farokhnia, and S. H. Fathi, "A method based on imperialist competitive algorithm (ICA) aiming to mitigate harmonics in multilevel inverters," *Proc. 2nd Power Electron. Drive Syst. Technologies Conf.*, 2011, pp. 32-37.

[18] J. Kennedy, R. Eberhart, "Particle swarm optimization", *Proc. IEEE Int. Conf. Neural Netw.*, 1995, pp. 1942-1948.

[19] I. Tsoulos, D. Gavrilis, E. Glavas, "Neural network construction and training using grammatical evolution," *Sci. Direct Neuro Computing J.*, vol. 72, no. 1, pp. 269-277, Dec. 2008.

[20] R. Eberhart, J. Kennedy, "A new optimizer using particle swarm theory," *Proc. 6th Int. Symp. Micro Machine Human Sci.*, 1995, pp. 39-43.

[21] A. Ajami, and M. Armaghan, "A comparative study in power oscillation damping by STATCOM and SSSC based on the multiobjective PSO algorithm," *Turkish J. Elect. Eng. Comput. Sci.*, vol. 21, no. 1, pp. 213-224, Jan. 2013.

Ali Ajami received his B.Sc. and M. Sc. degrees from the Electrical and Computer Engineering Faculty of Tabriz University, Iran, in Electronic Engineering and Power Engineering in 1996 and 1999, respectively, and his Ph.D. degree in 2005 from the Electrical and Computer Engineering Faculty of Tabriz University, Iran, in Power Engineering. Currently, he is associate Prof. of electrical engineering department of Azarbaijan Shahid Madani University. His main research interests are dynamic and steady state modelling and analysis of FACTS devices, harmonics and power quality compensation systems, microprocessors, DSP and computer based control systems.

Behrouz Mohammadzadeh was born in Tabriz, Iran, in 1987. He received his B.S. degree in power electrical engineering from Islamic Azad University of Ardabil, Iran, in 2010. He is currently M.Sc. student in Azarbaijan Shahid Madani University, Tabriz, Iran. His main research interests include the modeling and controlling of FACTS devices, power systems dynamics and optimization methods.

Reza Gholizadeh-Roshanagh was born in Ardabil, Iran on September 12, 1986. He obtained his B.Sc. degree (2008), in electrical power engineering from the Islamic Azad University of Ardabil, Ardabil, Iran. Currently he is Ph.D. student of Power Engineering at Azarbaijan University of ShahidMadani, Tabriz, Iran. He is also a member of Young Researchers Club, Islamic Azad.

Roozbeh Reza Ahrabi was born in Tabriz, Iran on March 23, 1990. He obtained his B.Sc. degree (2011), in electrical power engineering from the Azarbaijan University of ShahidMadani, Tabriz, Iran. Currently he is M.Sc. student of Power Engineering at Azarbaijan University of ShahidMadani, Tabriz, Iran.